

SPECIAL ISSUE

An Attempt to Increase Cognitive Performance After Stroke With Neurofeedback

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One of the dramatic sequelae of strokes is the impairment of cognitive functions. Standard rehabilitation programs do not always lead to an improvement. Based on theoretical considerations, the authors used alpha or theta neurofeedback training (NFT) in two different studies and assessed changes in the cognitive performance of the stroke patients. However, these two studies yielded incongruent results. Although in Study 1, alpha NFT was superior to a control treatment, this result could not be replicated in the second study. In Study 2, neither alpha nor theta NFT was superior to a control treatment. Given these conflicting results, the authors suggest that there is a serious need to perform future studies with comparison to a database and individual training protocols at selected electrode positions.

Introduction

A stroke occurs if, for any reason, the blood supply to a part of the brain is suddenly interrupted. This can cause physical, cognitive, or emotional impairments. With respect to our studies, it is important to mention that about 40% of stroke survivors show cognitive deficits. In many of these cases, memory that is used for daily life is seriously affected.

After the acute phase, cognitive rehabilitation plays a key role. Although there are many different kinds of potential cognitive trainings, there are divergent findings about the effectiveness of such interventions. Although Levin (1990) argued that cognitive training is “unproven but promising,” Wilson (1997) stated that “drill and practice” is senseless for patients with brain injury.

With respect to cognitive rehabilitation after stroke, neurofeedback training (NFT) might be a new and promising tool. NFT or electroencephalography (EEG) biofeedback refers to a specific type of biofeedback therapy in which participants learn to voluntarily regulate distinct parameters of their brain oscillations as measured by EEG.

Besides many studies indicating the effectiveness of NFT in the treatment of attention-deficit disorder/attention-deficit hyperactivity disorder (Kaiser & Othmer, 2000; Lubar & Lubar, 1999; Thompson & Thompson, 1998) or

epilepsy (Serman & Egner, 2006; Strehl et al., 2006), there are some reports indicating that NFT might be used to increase cognitive performance. For example, positive effects of NFT have been reported by Vernon et al. (2003), who found both working memory and attentional performance to be improved after training. Similarly, Egner and Gruzelier (2003) reported enhanced musical performance after NFT.

In his review, Klimesch (1999) outlined a clear relation between alpha and theta power and cognitive performance. Specifically for the upper alpha band, it has been reported that higher resting or reference power, as well as a more pronounced amount of power suppression (ERD) during a task, is related to good performance (Doppelmayr, Klimesch, Hödlmoser, Sauseng, & Gruber, 2005; Klimesch, 1999). Klimesch related upper alpha functionally to semantic memory processes and recently suggested a relation to top-down processing (Klimesch, Sauseng, & Hanslmayr, 2006). Although the lower alpha bands have been linked to attentional processes, theta has been associated with working memory. Based on these findings, Hanslmayr, Sauseng, Doppelmayr, Schabus, and Klimesch (2005) investigated the use of alpha NFT to increase cognitive performance. The results showed improved performance in a mental rotation task if the subject was able to increase alpha power by the means of NFT.

Because cognitive impairment after stroke is an important personal and economical factor, and because actual training programs do not reliably lead to positive results, the use of NFT could help a patient regain cognitive functions. Thus, we tested the hypothesis whether different types of NFT will help to increase cognitive performance after stroke.

Experiments

Two studies were carried out at the Department of Neuropsychology in the Rehabilitation Clinic at Medical Park Loipl, Germany. All participants were thoroughly informed, participated voluntarily, signed an informed consent, and received the standard treatment used in this clinic. Procedures that were specifically designed for the study

were performed in addition to the standard rehabilitation program. To be included, a patient had to fulfill the criterion of stroke and had to show cognitive impairment. To exclude patients with pseudo dementia due to depression, the ADS-L (General Depression Scale, Form L) questionnaire was applied (Hautzinger & Bailer, 1993).

The clinical rehabilitation program that is commonly applied includes computer training with either Rehacom or Cogpack. Both programs are designed to train attention, vigilance, language, and memory. In addition, several other therapeutic interventions (similar for all participants) took place.

To investigate changes in cognitive performance, two parallel versions of the Rivermead Behavioural Memory Test (RBMT; Wilson, Cockburn, & Baddeley, 1992) were used. The RBMT contains 11 subscales for everyday life situations, such as questions concerning orientation in time and space (date, location) or remembering an appointment, face, or name. In addition, several other tests were administered that will, because of the lack of space, not be reported here.

Experiment 1

Klimesch et al. (2006) reported that stronger upper alpha power in a resting or reference interval is related to better cognitive performance. Hanslmayr et al. (2005) also showed that an enhancement of upper alpha power in a reference interval can lead to increased cognitive performance. Thus, we hypothesized that an increase of alpha power by the means of NFT might have positive effects in restoring cognitive performance after stroke.

Method. Thirty-two participants (mean age = 56 years, $SD = 13$) were assigned to either a control (17 participants) or an experimental group (15 participants). The RBMT was applied before and after 10 days of training. In the meantime, every participant received computer training as well as either NFT or a relaxation training (autogenic training and progressive muscle relaxation). EEG was recorded at electrode position Pz using earlobe reference and a Procomp+ system. Signals were recorded for 1 minute with eyes open and eyes closed, followed by the NFT, which consisted of two 5-minute blocks. At the end of the session, EEG was again recorded in 1-minute segments with eyes opened and closed. Participants were instructed to increase alpha power and to collect as many points as possible. Alpha power was represented by an increasing/decreasing bar with a threshold line, and whenever the threshold was exceeded for more than 0.25 seconds, a point was added. According to Klimesch (1999), the frequency of the alpha band was adjusted to the individual alpha peak frequency ($IAF \pm 2$ Hz). The reward threshold was set one standard

deviation above the participant's alpha power at rest with eyes open.

Results. A two-way analysis of variance (ANOVA) with the factors Time (before and after training) and Group (NFT, control relaxation) was conducted. Significant main effects for Time, $F(1, 30) = 76.16, p < .01$, and Group, $F(1, 30) = 4.29, p < .05$, were found. Most interestingly, a significant interaction Time \times Group emerged, $F(1, 30) = 63.5, p < .01$, indicating that the increase in cognitive performance is more pronounced in the NFT group (see panel a of the Figure).

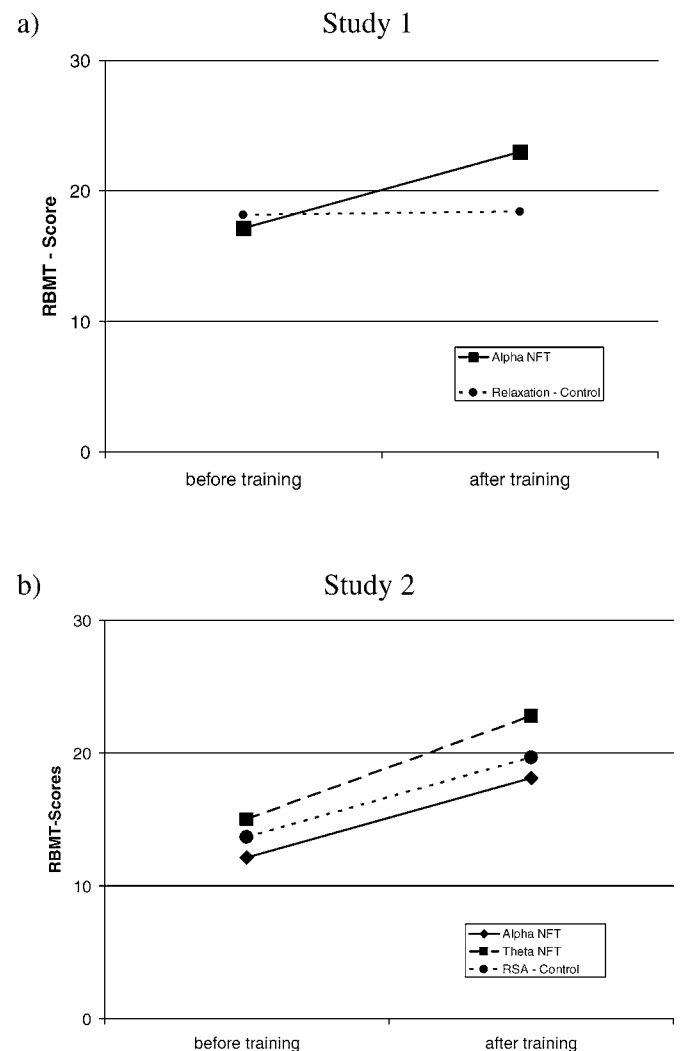


Figure 1. (a) Results of the first study. Significant main effects for Time and Group as well as a significant interaction were found. Although the Rivermead Behavioural Memory Test (RBMT) scores remained stable for the control group (dotted line), the values for the alpha neurofeedback training (NFT) group (bold line) increased from the beginning to the end of the rehabilitation stay in the clinic. (b) Results of Study 2. However, only the main effect for Time reached significance, indicating that the RBMT scores increased with the stay in the clinic. There was no difference in the effectiveness between alpha NFT (bold line), theta NFT (dashed line), and the control condition with respiratory sinus arrhythmia training (short dotted line).

Experiment 2

Cognitive impairment after stroke is to a great extent related to problems affecting working memory processes, which are reflected in the theta band (Klimesch, 1999). In the theta range, low prestimulus power and a high amount of power increase during the task are associated with good performance (Doppelmayr et al., 2005). Because stroke-related impairments may be due to either working memory (in the theta range) or long-term memory/top-down processing (alpha range), we compared three different training protocols: (a) decrease of theta power, (b) increase of alpha power, and (c) as a control condition, respiratory sinus arrhythmia (RSA) biofeedback training. The Table provides an overview of the designs of both studies.

Method. The alpha NFT group consisted of seven participants, the theta NFT group of four participants (unfortunately two additional participants had to be excluded), and the RSA group of six participants. On average, 8.5 sessions of training were completed by each patient. Technical EEG settings and the recording of resting EEG were identical to Study 1, and the NFT consisted of two 7-minute blocks. Feedback was given via a counter presented on a monitor. The counter increased in value whenever reward conditions were fulfilled for at least 0.5 seconds. The reward threshold was set automatically and was updated every 15 seconds. The threshold was set to that particular value that was exceeded for 35% of time in the last 30 seconds. For theta, NFT power had to remain below the (lower) threshold.

Results. A two-way ANOVA conducted for Time (before and after training) and Group (alpha NFT, theta NFT, RSA) revealed a significant main effect for Time, $F(1, 14) = 46.75, p < .01$, indicating increased performance at the end of the clinic stay. Neither the main effect for Group nor the interaction reached significance. For a better comparison with Study 1, the diagram is depicted in a similar way (see the Figure), although the interaction is not significant. Post hoc independent-sample *t* tests revealed a significant increase in RBMT scores for each training type (alpha: $t = -3.36, df = 6, p < .05$; theta: $t = -5.39, df = 3, p < .05$; RSA: $t = -4.65, df = 5, p < .01$).

Discussion

On the basis of theoretical considerations and in line with the findings of Hanslmayr et al. (2005), we assumed that NFT might assist the restoration of cognitive performance after a stroke. In both studies, RBMT scores increased during the clinic stay; however, the results differed considerably. The data of the first study were promising and clearly demonstrated a significant increase in performance only for the alpha NFT group. The fact that there was no advancement for the relaxation group, although they had the standard clinical rehabilitation, could be explained in accordance with the statements of Cappa et al. (2003). Cappa et al. argued that many of the cognitive training programs are inefficient and that performance increases might be simply due to placebo effects. In this study, alpha NFT proved a valuable

Table. Overview of the two study designs	
Study 1	Study 2
Day 1: entrance diagnostic	Day 2: entrance diagnostic
Days 2 to 11 (training period)	Day 2 until last, but 1 day (between 9 and 15 sessions NFT) (training period)
Experimental alpha group: Computer training 30 minutes Alpha (increase) NFT 2 × 5 minutes Control group: relaxation Computer training 30 minutes Relaxation 45 minutes (either autogenic training or muscle relaxation)	Experimental alpha group: Computer training 30 minutes Alpha (increase) NFT 2 × 7 minutes Experimental theta group: Computer training 30 minutes Theta (decrease) NFT 2 × 7 minutes Control group: RSA training Computer training 30 minutes RSA training 2 × 7 minutes
Last day: final diagnostic for study 1 on day 11	Last day: final diagnostic

Note. NFT = neurofeedback training; RSA = respiratory sinus arrhythmia.

tool for cognitive rehabilitation because it was superior to a control treatment that comprised the same amount of time, emotional support, or other potential placebo-related variables.

Study 2, however, revealed less supporting evidence for the effectiveness of NFT. Neither alpha NFT nor theta NFT was superior to the RSA (control group) training. The most plausible explanation of this result is that, despite the arguments of Cappa et al. (2003), the standard rehabilitation program, but not the specific training, was efficient in all groups. In this case, none of the three different training protocols were efficient or superior. A further possible explanation would be that computer training was not effective, but all three trainings had similar positive effects. Based on our conceptual model, we expected performance increases for the theta and the alpha NFT but did not expect a comparable increase for the RSA training. We are not familiar with any clear theoretical framework that could explain this cognitive benefit from RSA training.

The authors also attempted to assess whether increases in alpha power or amplitude correlated with cognitive improvements. The results were contradictory and even confusing, depending on which conditions and time frames were used to measure increases. Therefore, those results will not be presented here. Future researchers are encouraged to isolate whether any measured improvements depend more on the actual training process, on changes in power/amplitude, or on other factors yet to be determined.

In addition to these contradictory results, we must acknowledge several methodological shortcomings in both studies. The first shortcoming is the small sample size, especially in the theta NFT group. Furthermore, it would have been favorable to compare these data with two additional groups: first, a completely untreated waiting group and, second, a group of patients who received only the standard treatment program. Another methodological problem is the use of NFT at the fixed electrode position at Pz. A better approach might use a comparison of each participant's baseline with a database and the selection of training frequency and electrode site accordingly.

Summarizing, we can state that the use of NFT was effective in only one of two studies. Because of the methodological limitations of both studies, we cannot yet draw any reliable conclusions about the effectiveness of NFT for cognitive restoration in stroke populations, despite the significant improvements in Study 1. Nevertheless, NFT seems at least in part promising, and we will focus on this type of rehabilitation in future studies with more sophisticated methodology and a more elaborated study design.

In addition, there may be some value in including an RSA training condition in future studies as well, to rule out any possible efficacy of this intervention in the restoration of cognitive function.

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